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Color Coding of Amplitude Data as a Means of Improving Target Detection in Passive Sonar Displays

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PREFACE

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The research literature dealing with the use of color in passive sonar displays is neither extensive nor consistent. A thorough review has revealed that the properly designed and controlled experiment comparing color coding with monochrome in a dynamic sonar detection display has yet to be performed. Furthermore, the studies that have shown either no improvement or degradation in performance with the introduction of color, suffer from a failure to address two major variables.

Specifically, the simple superimposition of color on intensity (redundancy) may provide no additional information, while at the same time, too much color can add an additional type of masking (chromatic noise) to an already noisy display. The predictable effect of redundancy in this context is no improvement, while the predictable effect of chromatic noise is degradation of performance. It is proposed that color, introduced in a

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manner that avoids redundancy and minimizes chromatic noise, could improve target detection performance.

A two phase study was proposed to identify specific color codes that fit the above criteria and then to evaluate them against monochrome. The first phase required the creation of a color test display (CTD) to allow simultaneous presentation of color and monochrome sonar displays. The CTD has been set up in the Acoustic Display Research Facility (ADRF) and the selection of color combinations has been completed. For Phase 2, an experimental design has been developed for the controlled evaluation of the color combinations and a proposal has been submitted for funding to carry out the experiment.

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GLOSSARY OF ABBREVIATIONS

Abbreviation	Term
ADRF	Acoustic Display Research Facility
CTD	Color Test Display
CRT	Cathode Ray Tube
dB	Decibel
JND	Just Noticable Difference
LOFAR	Low Frequency Analysis and Recording
MDL	Minimum Detectable Level
MTFA	Modulation Transfer Function Area
Pd	Probability of Detection
Pfa	Probability of False Alarm
$\underline{r}$	Pearson Correlation
$\underline{r}_s$	Spearman Rank Correlation
RGB	Red-Green-Blue
ROC	Receiver Operating Characteristic
SNR	Signal-to-Noise Ratio
SUBACS	Submarine Advanced Combat System

COLOR CODING OF AMPLITUDE DATA AS A MEANS OF IMPROVING TARGET DETECTION IN PASSIVE SONAR DISPLAYS

INTRODUCTION

The Navy has chosen to use color displays in the advanced sonar systems currently under development. This has raised the question of how to make the best use of the color that is now available. Several reviews have dealt with the uses of color in general (e.g., Krebs, Wolf, and Sandvig, 1978; Teichner, 1979; Carter and Carter, 1981; Murch, 1984) and with the various types of displays with which color might usefully be employed (e.g., Butler and McKemie, 1974; Christ, 1975; Hansen, 1980; Neri and Zannelli, 1984). The consensus seems to be that color is here to stay and that, in many applications, there are or should be clear advantages over monochrome displays.

There is virtually a limitless combination of types of information to be displayed, types of coding to display it, and specific types of display devices. Of interest in this proposed research is one particular type of application, passive sonar; one class of format, the B-scan; and, finally, one specific display device, the RGB (red, green, blue) shadow mask cathode ray tube (CRT). The specific hypothesis to be tested is that, compared with monochrome, the use of color to encode amplitude information in unenhanced sonar displays of the B-scan type will facilitate target detection.

The present report consists of a literature search and analysis, based on which, there are two research phases. Phase I is comprised of an empirical determination of several sets of color codes that may enhance target detection, and an experimental design for the controlled evaluation of these color codes by direct comparison of target detection performance with color coded and monochrome grams. Phase II will consist of that experimental test, and will be conducted and reported at a later date.

BACKGROUND

B-SCAN

The B-scan is a rectangular, raster-type display in which one type of information, e.g., depth, bearing, or frequency, is plotted against another, e.g., range or time. For example, LOFARgrams (see figure 1) plot frequency against time with amplitude represented by intensity. It is updated by waterfalling the data lines from the top to the bottom of the gram. One of the major problems with such displays is the extremely high level of data density. As Hansen (1980) has suggested, more advanced systems may require even higher levels of data density and functional integration, and color coding may prove to be the only remaining option to control such complexity.

Because of the need to present more data in a limited CRT surface area and since the basic task of the sonar operator is to discriminate a certain few (generally fine) critical details from a dense mass of irrelevant noise, the most fundamental requirement of B-scan formats is high resolution. Until recently, one major drawback to the use of color for such systems was the inevitable performance trade-off in loss of resolution. Although this problem has been recently ameliorated, it has not been eliminated.

SHADOW MASK TUBE

Shadow mask technology for televisions and other display devices has been around since the 1950's. Recent advances in resolution have proved to be the major impetus for their consideration as sonar display devices. Before continuing, a distinction should be made. The term *nominal resolution* will refer to the theoretical limit of resolving power that is available, given the physical and electronic characteristics of the display device and peripheral equipment under optimal laboratory conditions and calibration. *Effective resolution*, on the other hand, will refer to the actual resolution likely to be available to the sonar operator during regular use.

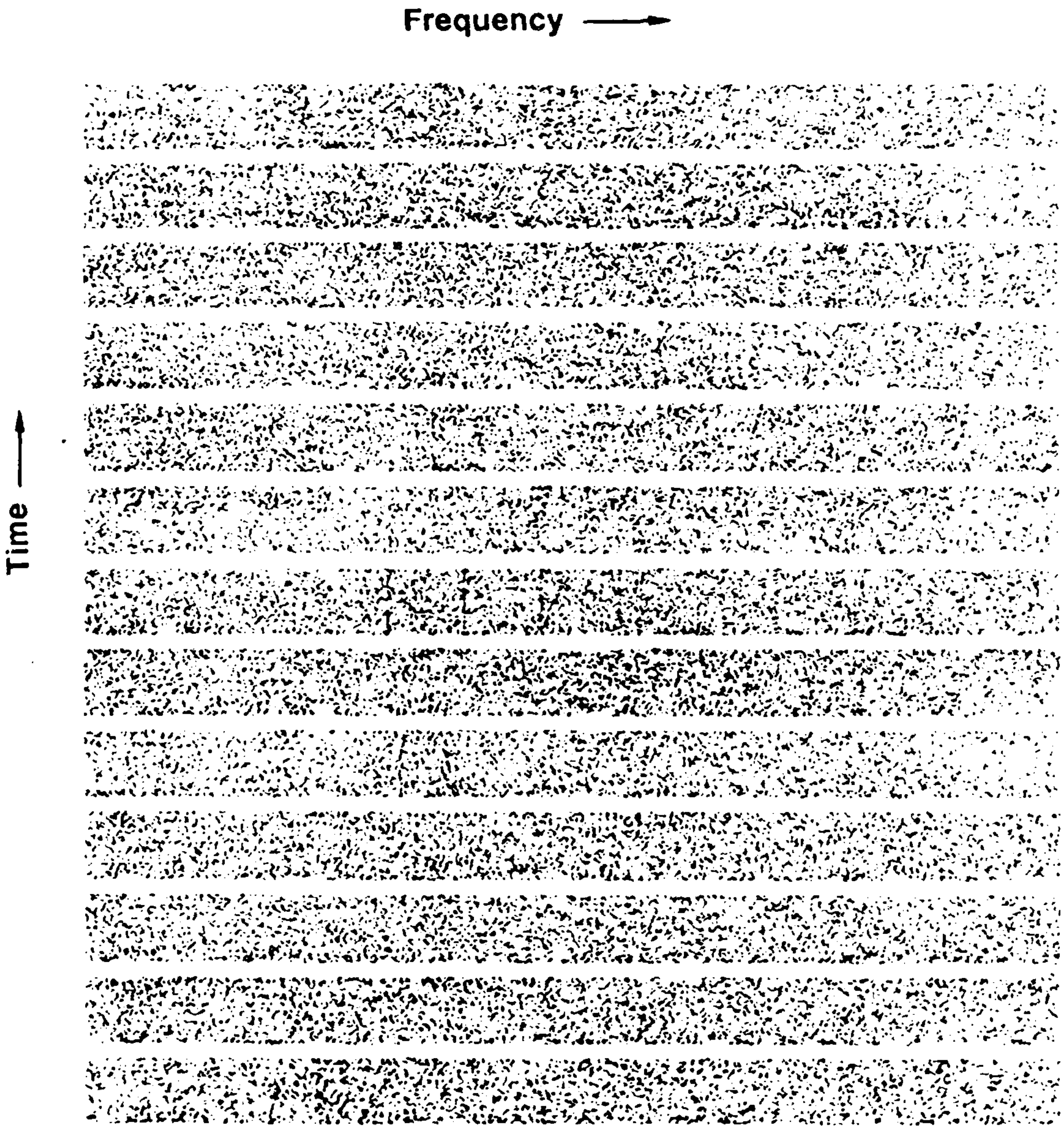

Figure 1. Representative B-Scan Display Format

The shadow mask color CRT monitors available at the NUSC/New London Laboratory Acoustic Display Research Facility (ADRF) are nominally capable of resolution that approaches the resolution of current monochrome monitors (1024 lines x 1280 pixels). The ADRF employs drive electronics (Ramtek 9400 display processor) that are capable of 100 lines per inch resolution. This degree of resolution, however, appears to exceed the capabilities of the currently available color monitors. For example, the monitors employed in the ADRF laboratory (Matsushita Standard Phosphor Type, 19 inch) have an array of holes (the shadow mask screen) through which the electron beam must pass on its way to exciting the phosphors. The holes that are aligned with the phosphor triads, one per triad, occur at a rate of 82 per inch, thus, reducing the effective resolution in comparison with the monochrome monitor. Problems may also arise in waterfall-type displays from the effects of misconvergence, e.g., the waterfalling action of data updates. As Hansen (1980) has noted, displays such as low frequency analysis and recording (LOFAR) and bearing time recorders (BTR) may present the most severe challenge for shadow mask CRT display systems.

The bottom line is that the effective resolution of the currently *available shadow mask monitor* is lower than that of the monochrome monitor. Evidence for this conclusion has come from two diverse sources, namely, an analytical/mathematical study (Infante, 1986) and a human factors study (Volkov, 1985).

Infante employed a measurement called the modulation transfer function area (MTFA). While indicating that the validity of the MTFA is not universally accepted, this researcher, nevertheless, calculated values of MTFA for monochrome and various color monitors, and concluded that if one wanted to design a shadow mask color display that was perceptually as sharp as a monochrome system, the color system would have to be able to scan substantially more lines in the same space. That is, according to MTFA measurement, the color monitor would have to possess a nominal resolution that exceeds that of the monochrome monitor in order to have an equivalent effective resolution.

The second line of evidence was provided by a recent NUSC study (Volkov, 1985) in which green and red LOFARgram displays on a shadow mask monitor were directly compared with a green monochrome display. This study involved the results of three simulated sonar detection experiments employing either static signals,

signals with varying amounts of Doppler (shifts), or complex dynamic signals characteristic of typical sonar signals. In each experiment, signals were presented under three display conditions, i.e., a green monochrome monitor, the green display on a color monitor, and the red display on the same color monitor.

Results were reported in terms of both the probability of detection (Pd) as a function of signal-to-noise ratio (SNR) for each display and the minimum detectable level (MDL), which is defined as the SNR value at which there was a 50% Pd and an acceptable probability of false alarms (Pfa). While the magnitude of the differences varied across the experiments, the direction of those differences was constant. In all three experiments, detection performance was best for the monochrome monitor, intermediate for the red display on the color monitor, and poorest for the green display on the color monitor. Although some of the differences were statistically significant, the functional significance of those differences was minimized. That is, it was concluded that there is little difference in performance among the three monitor-color combinations.

Though this conclusion may well be warranted, for present purposes the pattern is still important. In all three experiments, the monochrome monitor was associated with the highest level of performance. That this was not an artifact of the green color (the color to which the receptors in the eye are maximally sensitive) may be inferred from the slight red superiority over green on the color monitor. There could, of course, be complex display-observer interactions that might explain some of the differences (e.g., differences in response to the different persistence characteristics of the phosphors). Nevertheless, these findings support the contention that at the display-operator interface, current color monitor technology does not achieve the level of monochrome monitor resolution performance. Thus, one of the questions to be addressed in this research is the extent to which creative ways might be found to use the color variable to compensate for the lower resolution that seems to be inherent in the current color monitors.

Thus, the purpose of the proposed research is straightforward. If the effective resolution of the shadow mask system could be made to approximate that of current monochrome monitors and if the proper palette of colors to enhance B-scan formats can be determined, then operator performance could be enhanced. On the other hand, if the effective resolution of full-color systems is destined to

be lower than that of the monochrome, then the creative and effective use of the color that the system makes available may be the best or perhaps the only way to compensate for the deficiency. While this alternate goal may seem less satisfactory, it should be pointed out that future color monitors will possess higher resolution. Thus, what may be compensation in today's system will inevitably be enhancement in tomorrow's.

There is yet another goal that while farther removed from the more obvious ones just stated may be just as important. If it can be shown that the selective introduction of color in the waterfall-type display at least does not degrade performance, such an outcome might provide sufficient grounds for reexamining the quantization parameters that go into the creation of the eight currently employed intensity levels. The reason for this is that the current quantization schema was developed to optimize target detection on a monochrome display. If a color system can perform equally well using the monochrome schema, then it may be possible to enhance performance with a quantization schema specifically designed for a color display.

COLOR IN SONAR DISPLAYS

PREVIOUS RESEARCH: GENERAL

In all the literature surveyed on the use of color in sonar and related displays, one conclusion seems universal. The choice of whether or not to use color, which colors to use, and how to use them is inextricably intertwined with the nature of the information to be displayed, the nature of the display, and the context in which the display is to be used. Each situation is unique. Furthermore, while there are some general guidelines for the use of color in a variety of alphanumeric and graphic displays (e.g., Neri and Zannelli, 1984), there have been no clear or consistent findings regarding the use of color in the type of sonar display that is the focus of the present study.

Butler and McKemie (1974, pp. 2-4) reported that, "Although an extensive literature exists on human color perception and color preferences, and although a number of investigators have reported favorable performance results obtained with color display implementations, no specific guidance for the choice of colors for use in a sonar display was obtained from the literature survey." They further

stated that, "Although several investigators have published general display design criteria and even a few have considered more specific sonar display applications, no useful guidelines for the employment of color in a sonar display were found."

After an extensive series of experiments on the use of color to code amplitude information in sonar displays (which will be summarized later in this report), the same authors concluded that, "The extent to which a particular color code (or for that matter the use of color itself) will result in improved performance, if indeed it does, over a monochromatic display, will obviously depend not only on the colors selected but also on the display format, data statistics, the observer's task, and the observer himself. These latter factors can be expected to be just as important, if not more so, than the factor of color selection for most display applications" (Butler and McKemie, 1974, pp. 2-6). Ten years later, Kraiss and Kuttelwesch reported that, "In spite of several publications addressing this problem, it is still rather unclear whether color is of any help in sonar displays" (1984, p. 68).

Neri and Zannelli have summarized the situation with specific reference to sonar B-scan formats most clearly as follows for Submarine Advanced Combat System (SUBACS) displays. "In light of the lack of experimentation in this area . . . it is recommended that the present format of several intensities be used until further investigation reveals whether or not color coding will improve performance. Using several intensities of a single color appears to be a natural way to differentiate quantitative data. The use of color in raw data would be primarily an attempt to improve the operator's detection ability. There is, as yet, no evidence to suggest that the use of color here would be beneficial, and if used improperly it could be detrimental." (1984, p. 11).

Given this state of affairs, it is not unreasonable to inquire why the issue of color coding of amplitude in sonar displays should even be pursued further. There are many answers, but they reduce to a few basic principles. First, as previously stated, color may be the one remaining option for directly enhancing such displays, if indeed they can be enhanced. Second, such enhancement may be the only recourse to regaining the performance lost in some applications with some color monitors. Third, a consideration of some variables that have not yet been accorded the degree of importance that they de-

serve in this context, may suggest more creative ways of employing color than have heretofore been attempted.

The number of studies that have addressed the specific issue of color coding of amplitude data in sonar displays is very small. Hindsight being 20-20, it is now apparent that these studies had some serious limitations, so that the results must be characterized as ambiguous at best. It is to these studies that we now turn briefly. One study by Butler and McKemie (1974) of Tracor Sciences and Systems, under contract to the U.S. Navy, and another by Kraiss and Kuttelwesch (1984) at the Forchunginstitut fur Anthropotechnik in Germany, reported in the Society for Information Display Digest (SID 84), are particularly relevant to the proposed research.

BUTLER AND McKEMIE STUDY

It should be mentioned at the outset that the Tracor document (Butler and McKemie, 1974) is the result of a large and multifaceted undertaking. Even though it is 14 years old, it nevertheless contains valuable information on color specification and measurement; an extensive review of the human color perception literature; a glossary of colorimetric, radiometric, and photometric concepts; and engineering guidelines for color display design; etc. The present focus is the series of experiments conducted at the Tracor Color Display Facility, which have a direct bearing on the issue of the color coding of amplitude information in sonar displays.

The Tracor experiments began with the establishment of a base set of 46 colors chosen from the 512 colors (combinations of three primary colors and eight intensity levels) available for display. The base set was chosen based on judgments of a three member panel, the criterion being that each color be perceptually distinct from each other color, whether displayed side-by-side or simply on the display simultaneously. Each color in the base set was then identified by its approximate position (x and y chromaticity coordinates) on the 1931 CIE Chromaticity Diagram. The luminance (Y) of each color, which was measured directly from the CRT, was also listed.

Next, employing the psychophysical method of Paired Comparisons, 12 subjects ranked the 46 colors in conspicuousness, a scale defined by the Tracor scientists in terms of the following operations. Each of the 1035 combinations of color pairs were presented to each

subject on the CRT display in a checkerboard pattern, with larger patches of each color presented below the checkerboard. The subjects were required to choose that color of each pair which "would best represent a large amplitude signal in a z-axis color coding scheme." It should be mentioned that the authors of the report did recognize and attempt to control the problem of differential contrast-enhancement effects that are inherent in such a display. After resolving ambiguities that resulted from variation in rankings of the different subjects, a sort of Average Conspicuousness Rank was assessed for each color.

It is interesting to note at this point that when the conspicuousness ranking was compared to the luminance (brightness) ranking, it was stated that "the rankings are significantly different," even though no statistical analysis was presented to substantiate such a conclusion. This statement was all the more puzzling in light of the fact that the Spearman Rank Correlation between conspicuousness and luminance turned out to be quite high, r_s=.94, p<.001. When one considers that this correlation accounts for 88% of the variation and that the remaining 12% could easily be due to the ambiguities and averaging involved in the creation of the scale, it seems improbable that differences in conspicuousness reflect much more than simple differences in intensity.

The next step in the Tracor research was to devise several color codes. These codes would be tested employing a single standard condition which (for better or worse) was considered to be a fairly representative one for passive sonar applications. The standard condition consisted of a static display with the the following characteristics:

-- Format: Generalized (with 95 beams or spectral channels displayed horizontally and 100 time updates displayed vertically).

-- Observer Task: Detection of up to six targets (or up to six target lines).

-- Data Statistics: Gaussian.

-- Minimum Design SNR: -5 to -6 dB.

-- Number of Colors: Seven or eight.

-- Thresholds: First at mean of noise, remainder in increments of 0.5 standard deviation of the noise.

A total of seven color codes (Code I through VII), each consisting of either seven or eight colors, were devised with various criteria in mind. These criteria and other specific details of the color codes will be discussed along with the test results. The test consisted of the presentation of simulated sonar data in one of seven color codes or the achromatic code (seven levels of intensity along a grey scale) to a total of nine trained observers. The performance measure, i.e., MDL, was the SNR required for the signal to be detected in 50% of the trials in which it was present or a Pd of 0.5. Although the reader will be spared the complex array of display characteristics and experimental details employed during testing, the following seemed important enough to mention. First, the simulated sonar data were presented in 8 blocks of 25 frames for a total of 200 frames per subject. Each frame was presented for 60 seconds and consisted of a static display (i.e., no real-time update). Each set of 25 frames employed one of the seven color codes for amplitude, or achromatic code, and the sets were presented in a partially counterbalanced order.

The results of the tests were presented as seven graphs with Pd plotted against SNR. Each graph presented the data for one of seven color codes along with the data for the grey scale. The reason for this particular juxtaposition of curves is obscure, since the reader is warned that the grey-scale code "in no sense necessarily represents even a near-optimum achromatic scheme." Thus, in each graph the appearance of color code superiority over the grey scale is an artifact of the inadequacy of the grey scale itself. The only comparisons that are legitimate for the study are comparisons of the relative performances of the color codes among themselves.

With this caveat in mind then, the results are clear. The color codes which were associated with the best performance (Codes III and V) were those which possessed several common characteristics, i.e.,

-- Both codes contained a series of colors that were linear in conspicuousness and covered a wide range of conspicuousness values.

-- For both codes, conspicuous rank correlated almost perfectly with luminance rank, *r*=.99 for Code III; *r*=.98 for Code V.

-- All other codes had properties which intentionally (in most cases) violated order or logic in one or more ways. For example, Code IV began and ended with colors of the same dominant wavelength; Codes IV, VI, and VII were nonmonotonic in conspicuousness (luminance); and so on.

In an attempt to identify any other salient features of Codes III and V, we located the colors on the 1931 CIE Chromaticity Diagram and then gave them verbal labels from a chart of color names (Kelly, 1943). Interestingly, it turned out that in each case the lowest three amplitudes were coded into quite distinctive, highly saturated colors, while the remaining amplitudes were coded by mixtures of less distinctive, relatively unsaturated colors. Thus, the two codes represented patterns of color use which inadvertently may have gone beyond the intentions of the investigators. These characteristics will be discussed at length later. However, it is important to reiterate at this point that the Tracor report did not attempt to contrast color with monochrome for *sonar displays*. Thus, there is no basis for concluding that any of the color scales employed in the study even approached the performance level of a normal monochrome display.

KRAISS AND KUTTELWESCH STUDY

In this experiment (Kraiss and Kuttelwesch, 1984) sonar target identification performance was assessed as a function of seven scales (Scale 1 througrh 7) differing from each other in the presence or absence of color, in chrominance (measured in terms of just noticeable differences (JNDs) for color discrimination), and in luminance (measured in JNDs along an intensity continuum). The scales consisted of from two (dark and white) to twelve colors (actually six colors, each presented at two different intensities). Each of the twelve subjects was presented with three repetitions of the test display. Each display consisted of one of three variations of background noise variance (i.e., 0%, 8%, or 16%) presented, respectively, at one of three SNRs (i.e., 0.055 dB, 0.4 dB, or .08 dB). In each test display, there were eight background bands presented in one of the seven color scales, with targets superimposed as vertical lines

in one of three positions within a band. The signal probability was 50% for any one band in any one test. Subjects were instructed to indicate whether they had seen a target within each of the eight bands.

Results were presented as receiver operating characteristic (ROC) curves for each noise/SNR condition. Areas under the ROC curves for each scale were then plotted against the SNRs. The results indicated that when no color (dark and white) or a minimum of color (e.g., red, yellow, and green) were employed (Scales 1-4), tracking performance was about equivalent. When seven colors were employed, coded according to intensity but not ordered according to wavelength and with white at both the low and high intensity ends (Scale 5), performance was slightly degraded at all three SNRs. For the final two conditions (Scales 6 and 7) where neither intensity nor color were coded in an orderly, sequential manner, performance was best in the no noise condition but degenerated precipitously to the lowest performance level with the introduction of noise.

The authors suggested that the differences in performance were due to the operation of two confounding variables. First, the degraded performance for Scale 5 *(an unanticipated outcome)* was attributed to chromatic aberration, because red and blue colors appeared in neighboring bands of the display. The severe degradation of performance for Scales 6 and 7 when noise was present was attributed by the authors to the camouflage effects of chromatic noise. The conclusion, not surprisingly, was that there was no indication from the data that color could facilitate this task.

While such a conclusion is surely warranted by the data, some aspects of the experimental design render the data of limited value in addressing the basic question about color in passive sonar displays. The major problem stems from the display itself which, as in the Tracor study, appears to have been static. Time and again, we have been warned that if color is to be given a proper test, the simulated test conditions must mimic as closely as possible actual sonar displays. Additionally, many more potentially confounding variables were present in the experiment. First, information redundancy (to be discussed in the next section) is a potential source of difficulty in Scale 5 and perhaps others. Second, a baseline condition for comparison purposes, similar to that of current sonar displays was missing. Third, Scale 6 contained far more than an optimal number of color/intensity levels. And finally, some of the color codes

employed, especially Scales 6 and 7, may have provided information conflicting with, rather than augmenting, the usual amplitude :: intensity relationship.

CRITICAL VARIABLES IN DETERMINING A COLOR SCHEME

As can be seen, both the Butler and McKemie and the Kraiss and Kuttelwesch studies are open to criticism on a number of grounds. First, both studies employed static displays, a fact which alone renders the results of limited value. Second, neither study employed a baseline control condition that approximated current monochrome displays, so that unambiguous conclusions about the relative effectiveness of color codes were not possible. Third, in the German study, since the color codes themselves were not varied in systematic ways, the implications of the results are not at all clear. Finally, in the Tracor study, while there were statistically significant performance differences between some of the color codes, the functional significance of these findings is questionable. In general, the differences of average MDL values from the worst scale to the best were relatively small. In addition, the statistical test employed to compare scales (the Wilcoxon matched-pairs, signed-ranks test) as applied to the Tracor data, guaranteed an inflated number of significant differences.

The only conclusion that is justified at this point is that the question of color enhancement of passive sonar displays is still wide open. Since the available literature and research have shed so little light on the question, we have decided to address it in a different way. Heretofore, researchers have been asking what colors might be used to enhance a passive sonar display and how might they be used? As straightforward and obvious as these questions may seem, they may be the wrong questions. Instead, we have chosen to ask a different question, namely, what are the limitations at the display-operator interface that must be overcome if color is to be used effectively as a coding device for passive sonar?

A review of the literature in both information processing and color vision points to two major variables that must be considered and the limitations they impose must be addressed. The variables are information redundancy and chromatic noise.

REDUNDANCY IN INFORMATION PROCESSING

There is a well known principle that has a significant bearing on the current problem. While it is often cast in information processing language, it is, nevertheless, such a fundamental aspect of brain function that it is demonstrable in organisms as low on the neuro-developmental scale as rats and rabbits (Kehoe, 1987; Salafia, 1987; Solomon, 1987). The principle, simply stated, is that when presented with information that is either redundant or irrelevant to the task at hand, the brain automatically tunes out that information. If the information continues to be presented, the strength of the inattention (tuning-out) increases; and if the information subsequently becomes relevant or nonredundant, it becomes necessary to unlearn or extinguish the inattention.

Before proceeding, it is important to note that redundancy does have its place in a variety of display systems. For example, hostile, unknown, and friendly vessels are often coded, not only with specific symbols, but also in red, yellow, and cyan colors, respectively. While the color code does not convey information in as much detail as the icons, it still facilitates information processing, for example, by permitting more *rapid initial identification* of objects in a dense display or grouping of similar information types.

Nevertheless, the crucial importance of redundancy to the issue of color coding of passive sonar displays is inescapable. Amplitude data, coded into intensity, may already contain sufficient information for the sonar operator to perform his discrimination task at an asymptotic level of proficiency. All other things being equal, further coding of this information by the introduction of a color code would be redundant, and, according to the redundancy principle, there should be no increment in performance.

Although there is no unanimous agreement on underlying mechanisms, this sort of tuning-out process can often be distinguished from selective attention, the process of actively directing one's attention toward a particular source of information. Actually, such active attention processes may summate with the more passive tuning-out process in a manner to virtually guarantee that the redundant information will not enhance the discrimination process.

Unfortunately, it is not possible to separate the contribution of redundancy from that of other variables in the results of previous

studies of color and passive sonar. Nevertheless, it is a virtual certainty that the variable has influenced those outcomes. The simple overlay of a color code upon an already existing and quite functional intensity code for amplitude information is redundant and is likely to be responded to as such by the sonar operator. And in some cases, as we have seen (Butler and McKemie, 1974; Kraiss and Kuttelwesch, 1984), if the color code presents different or conflicting information, it can even degrade tracking performance.

CHROMATIC NOISE AND CAMOUFLAGE

While the term chromatic noise has been used before in this paper and while the meaning may be intuitively obvious, no adequate definition was found in the literature surveyed. It is such an important concept in the present context, however, that we will attempt to provide an acceptable objective definition.

First, visual noise refers to any random output of a visual display analogous to auditory noise. If this output is in black, white, and shades of grey, it is achromatic noise, a typical example of which is the "snow" seen on a television set tuned to a channel that is not currently broadcasting. Chromatic noise is more difficult to demonstrate since, even on a color television set, the noise tends to be achromatic. An approximation may be seen, however, by tuning a very distant station wherein the color is present but the picture is lacking in clarity and definition. Alternatively, mistuning a local channel will sometimes work. Thus, a display of chromatic noise is one in which the "snow" is in color.

One may think of camouflage as not only the most obvious, but also the ultimate use for chromatic noise. And that is precisely the problem in passive sonar displays. Chromatic noise adds its own characteristic type of visual masking to the masking already inherent in achromatic noise (e.g., Aiba and Granger, 1985; Poulton and Edwards, 1980). This additional masking is not easily overcome and the fact that the targets are coded in color does not aid in overcoming the additional color masking effects.

DETERMINING A COLOR SCHEME FOR PASSIVE SONAR

While redundancy and chromatic noise do not nearly exhaust the list of relevant variables, the simple fact is that no attempt to color code amplitude information in passive sonar displays has even the slightest chance of being successful without, first and foremost, taking account of these two variables. Having devised a scheme that eliminated redundancy, and minimized chromatic noise, one would at least be in a position to evaluate the degree of enhancement of performance, if any, or at least to discover what other variables might still be confounding the process.

With these admonitions in mind, the color codes to be employed in the present research will possess the following characteristics.

1. To minimize chromatic noise, a maximum of four colors will be employed to code amplitude.

2. The three lowest amplitude levels (not counting zero) will be coded into different colors, since enhancement of these would be most *likely to improve performance*.

3. The highest four amplitudes will be coded in the same color.

4. The specific colors used, will be chosen to maximize visibility and discriminability while at the same time minimizing the influence of chromatic aberration.

5. The spectral order of the colors will correlate with intensity, so as not to present conflicting information.

6. The three lowest amplitudes that are now color coded, will be displayed at higher intensities than normal. That is, since they are discriminable from the higher amplitudes by color, they may now be enhanced by raising their intensities, without fear of confusing them with the high amplitudes.

Judicious application of these principles suggests several possible color enhanced display formats. Figures 2 through 5 illustrate some of the possibilities. Figure 2 depicts the normal state of affairs in a B-scan sonar display, with amplitude quantized into 8 levels and displayed as eight levels of intensity (starting at Level 0

through Level 7). Each succeeding intensity level, with the exception of Level 0, has a $\sqrt{2}$ relationship to the immediately preceding level. Thus, for example, if Level 1 has the value a, then Level 2 = $\sqrt{2} \times a$, Level 3 = $2 \times a$, etc. This normal state of affairs will be referred to as Code 1.

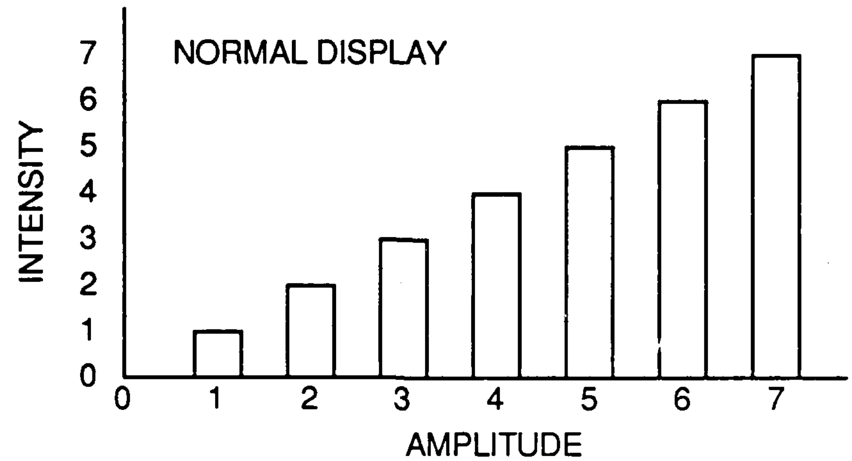

Figure 2. *Display Intensity Plotted Against Amplitude for the Normal B-Scan Display Code 1*

Code 2, depicted in figure 3, simply adds different colors to the first three levels. The listed colors (Red, Yellow, Green, and Cyan) are at this point for illustrative purposes only and many other color combinations might fit. Specific colors are to be determined empirically.

Figure 3 is presented only to indicate where color would be employed. The reader will recognize that the code violates the redundancy principle by simply adding color to the already available intensity information. (It is possible that the information value of intensity at the lowest levels may be sufficiently low so that the colors might not be totally redundant and, thus, might add a small increment to performance. On the whole, however, the increment should be minimal and more optimal schemes are almost certainly available.

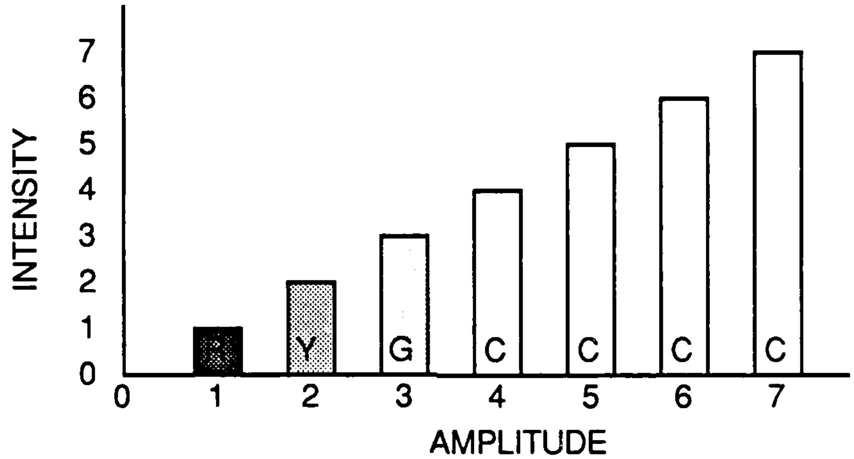

Figure 3. Display Intensity Plotted Against Amplitude for Color Code 2

Code 3 (figure 4) is expected to produce, at best, moderate enhancement because, while it does introduce color and thereby permit *amplification* of intensities, it does not amplify the intensities differentially. Thus, regardless of the level of intensity chosen (any level from 1 to 7 could replace Level 6 in this example), Code 3 simply involves a partial substitution of color for intensity. It does not make use of the information inherent in intensity differences.

Code 4 (figure 5) illustrates one possible variation on both addition of color and manipulation of intensities. This code not only introduces different colors at the three lowest amplitudes, but also amplifies the intensity information differentially. As before, the intensities depicted are examples, and the actual intensity differences will be determined empirically.

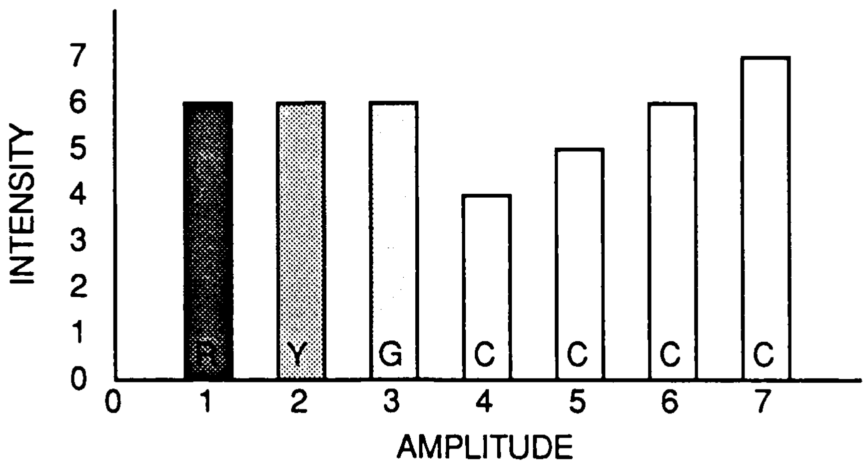

Figure 4. Display Intensity Plotted Against Amplitude for Color Code 3

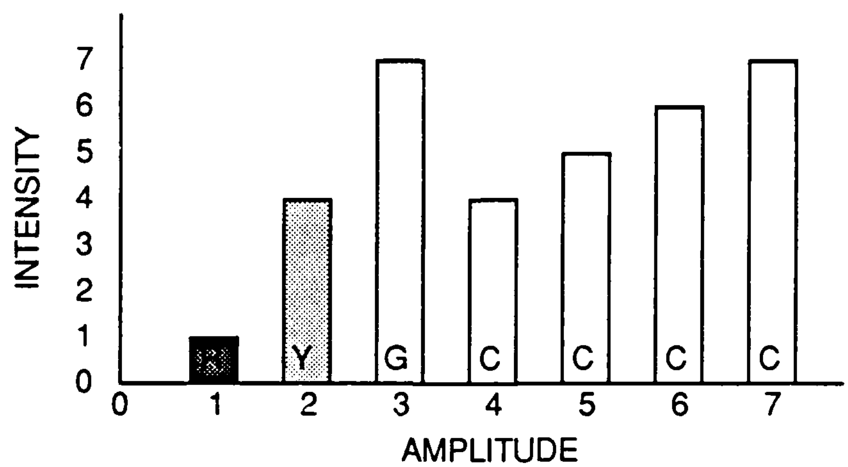

Figure 5. Display Intensity Plotted Against Amplitude for Color Code 4

It should be clear, of course, that many additional variations on these themes are possible. Experimentation with at least several codes will be necessary. Initially, this research will focus on codes, such as Code 4, that seem intrinsically to have the highest probability of success.

SPECIFIC COLORS

As stated so often, both in the literature and previously in this report, there is no palette of colors for the present purposes that is backed by compelling logic, research, or theory. Much like predicting the weather, there are so many variables and interactions among the variables, that the color choices are chancy at best. However, for the first phase of the research, which consists of the empirical determination of potentially valid color combinations, a four-color code is suggested as the starting point. This particular combination was chosen for a number of reasons that seemed at least reasonably consistent with the bulk of available logic, research, and theory. The colors are red, yellow, green, and cyan for the coding of Amplitudes (levels) 1, 2, 3, and 4-7, respectively. The specific characteristics of each color are determined to a major extent by the electron guns and phosphors employed in the color monitors. The reasons for the choice of these colors are as follows:

-- They cover a wide band of the visible spectrum.

-- They are highly visible and discriminable one from another

-- Red and green can be generated employing one gun and one phosphor each, a possible aid to discrimination.

-- Yellow and cyan require the use of only two guns and two phosphors.

-- Red is the choice for coding the lowest intensity because the red gun must be driven at a proportionally higher voltage than the green to achieve comparable luminance. Also, Volkov (1985) found a slight red superiority over green for the detection of sonar signals in his recent study.

-- In this scheme, the color blue is avoided entirely, not only because it is not needed, but also because of the visual acuity and chromatic aberration problems that its use could create (Neri and Zannelli, 1984).

There are, of course, many additional reasons for choosing this array of colors, but the stated ones seem to be the most relevant. It is important to reiterate, however, that there is no strong commitment to this specific array. It will simply be the starting point in the empirical determination of the most appropriate codes.

A WORD OF CAUTION

Before proceeding with the specific research methods to be employed, an important point needs to be made regarding the logic and limitations of hypothesis testing procedures in regard to research of this sort, namely, that the outcome of the experiment is, by definition, unidirectional. The experimental hypothesis can be confirmed, but it cannot be contradicted. That is, if the hypothesis that the *judicious* use of color can enhance passive sonar displays is correct, data can be gathered to support it. There should be a statistically reliable difference in operator performance with the color enhanced display in comparison with the monochrome display. On the other hand, failure to support this hypothesis, i.e., failure to find performance enhancement with color, does not necessarily prove that color cannot enhance performance with such displays. It could merely mean that the correct color/intensity combinations have yet to be discovered.

This is, of course, an intrinsically unsatisfactory state of affairs, but fortunately there are a number of mitigating circumstances. Whereas it may be impossible to prove the absence of an effect, nevertheless, the continuing accumulation of negative evidence eventually tends to build a strong case. We may be at about that point with color and passive sonar. The Tracor study (Butler and McKemie, 1974) showed that some color scales were better than others, but not whether color was better than monochrome. Kraiss and Kuttelwesch (1984) found no evidence that color could enhance performance. Most importantly, every paper that could be found having anything to do with color in passive sonar, contained warnings

about the sensitivity of such displays to degradation by the inappropriate use of color.

In this report, an attempt has been made to analyze the available research, to point out some limitations in its applicability or generality, to indicate the variables thought to be of major concern, and to synthesize this information into a set of color codes that has at least a reasonable probability of enhancing operator performance, *if indeed it can be enhanced.* After testing these codes, if no statistically significant, and more importantly, functionally significant improvement in performance can be demonstrated, then it may be time to simply concede that in this instance, the monochrome display is not likely to be improved upon.

PHASE I: EMPIRICAL DETERMINATION OF COLOR CODES

Although an attempt has been made to predict what color codes might have a reasonable chance of enhancing the display, what was needed at this stage of the project, and what had apparently not been available to previous researchers, was *a sonar simulation that permitted the juxtaposition of two grams which were identical, except for the presence or absence of color.* Therefore, the first phase of the research involved setting up a color test display (CTD) to permit independent manipulation of both color and intensity of all amplitude levels of a typical passive sonar display.

COLOR TEST DISPLAY

The CTD (figure 6) provided two display formats, each of which displayed information in both monochrome and color. The lower format consisted of 2 rows of 7 patches each. The upper row displayed the 7 fixed green monochrome intensities, while the lower row displayed the 7 independently variable patches. Each variable patch could be assigned a specific color/intensity value by entering a number between 000 and 255 for each primary color (red, green, and blue, respectively). Thus, for example, a bright red might have the values [240-000-000], while a yellow of medium intensity might be [135-135-000], etc. For comparison purposes, the monochrome intensity values were 045, 075, 105, 135, 165, 195, and 240.

Next, a series of 8 signals were generated in 2 simulated sonar displays, at SNRs ranging from -6 dB to +1 dB in integer units. These signals scrolled onto the upper portion of the screen in both monochrome and the selected color code, for a period of 18 seconds, after which the displays (60 lines each) were frozen and the target locations identified with markers. At this point any or all of the colors or intensities of the variable display could be changed, and the effects immediately noted, both in the patches and in the color gram. After making whatever changes seemed warranted, a new set of targets could be selected and the above process repeated, as often as desired. Thus, it was possible to directly compare monochrome and color codes and to see immediately whether a change in the color display produced any change in the appearance of the targets.

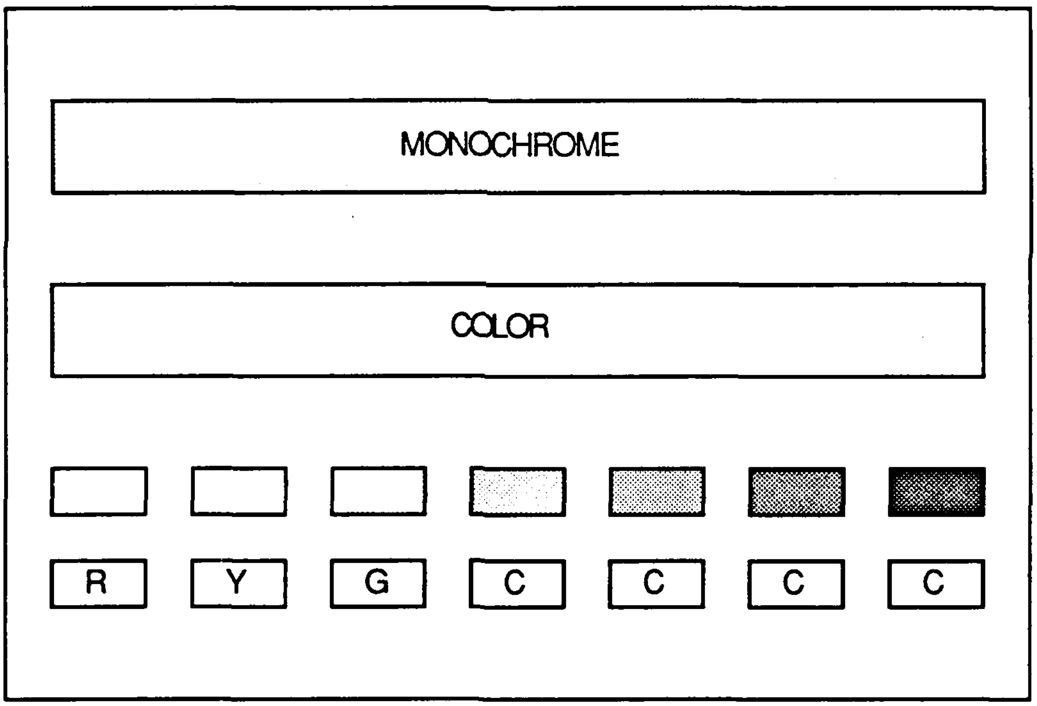

Figure 6. Display Used to Determine Color Codes
(Upper two frames are gram displays, while the small frames at the bottom indicate the monochrome and color codes in discrete patches.)

METHOD

The procedure for this phase of the research consisted of setting up a specific color coded display on the CTD and then rating it for enhancement, no difference, or degradation, in comparison with the monochrome display. If a code was rated *no difference*, a small adjustment in color and/or intensity would be made and a new rating assigned. Changes would continue to be made in a systematic way employing this variation of the Psycho-physical Method of Limits until the rating changed. If the new rating was *enhancement*, the values would be noted and further variation attempted in order to maximize the effect. If the new rating was *degradation,* it was noted and there was no further variation in that direction.

Since this was the exploratory phase of the research, the purpose of which was to identify color codes or classes of codes to be evaluated later in a controlled experiment, it was felt that it would be best carried out by one individual employing a single set of criteria for judgment. Thus, these procedures were carried out by one of the authors (Salafia) over a period of 9 sessions, each session lasting from approximately 30 minutes to 2 hours.

RESULTS AND DISCUSSION

Since several hundred different color/intensity combinations were evaluated in this phase of the research, the first problem we had to face was how to present the findings. It was determined that an efficient form of presentation would be to summarize the results first in terms of a few basic principles and then to present the several specific codes that appeared to have the greatest likelihood of enhancing target detection.

The basic principles appear to lend considerable support for the color coding concepts presented earlier. First, several attempts were made to introduce more than 4 colors. In each case, and regardless of the specific colors chosen, degradation occurred. We concluded, therefore, that 4 is indeed the maximum number of colors that should be employed in this type of sonar display. While 4 was the maximum, it was not necessarily the optimum number. It appeared that fewer than 4 colors, if carefully selected, sometimes produced enhancement. This will be discussed later.

Second, various attempts were made to reverse the coding by using multiple colors for the upper rather than the lower range of amplitudes. While many different colors and color sequences were attempted, none produced any visible enhancement and virtually all appeared to produce degradation in comparison to the monochrome display. Using multiple colors for the middle of the amplitude range had similar adverse effects. Again, it was concluded that the decision to employ different colors only at the lower end of the amplitude scale was the correct one.

Third, when the same color combinations using Code 4, in which amplitude differences were coded into both color and intensity, were contrasted with Code 3, in which differences were coded into color only, Code 4 always proved superior. Thus, again in agreement with previous reasoning, maintaining an amplitude-intensity relation seemed to be best.

Before proceeding with the specific color combinations chosen for further research, a word of caution is in order. We cannot emphasize strongly enough that while every effort was made to be as objective as possible in the selection of colors, this phase of the research was nevertheless open to effects of experimenter bias. Before any firm conclusions can be drawn, the controlled experiment of Phase II must be conducted.

In choosing the color combinations, several additional criteria were employed that could not be foreseen until the CTD became available. First, considering only the monochrome display, it was noted that targets at the highest 3 SNRs (+1, 0, and -1 dB) were almost always detected immediately and errorlessly. On the other hand, targets at the lowest 3 SNRs (-4, -5, and -6 dB) were almost never detected, even when their locations were identified by markers. It was with targets at the middle 2 SNRs (-2 and -3 dB) that there was a substantial degree of variation in detectability. These middle values, therefore, became the focus of attention.

When color was introduced, the first step was to see that there was no reduction in detectability of targets at the upper SNRs. Only then would attention be directed toward the other SNR levels, with particular emphasis on the middle values, in making further judgments. Employing the procedures outlined in the method section and the above criteria for judgment, 5 specific color-intensity combina-

tions (table 1) were identified, which were judged to merit further study.

Several consistencies may be seen in these 5 combinations. First, in all 5 cases, the intensity settings of the first 3 amplitudes have been raised by 2 levels, in comparison with the corresponding monochrome values. In each case, these values seemed superior to both lower and higher values. Second, the first 2 combinations employ four colors and are very similar. The only difference is that in Combination 2, the second amplitude is coded amber, rather than yellow. This was done because in Combination 1, yellow did not appear, perceptually, to be very different from green. Target detection performance, however, seemed about equivalent for these combinations.

Table 1. Five Color-Intensity Combinations for Study in Phase II Identified by Their RGB Settings

AMP	COLOR-INTENSITY COMBINATION				
	1	2	3	4	5
1	RED	RED	YELLOW	YELLOW	GREEN
2	YELLOW	AMBER	YELLOW	YELLOW	GREEN
3	GREEN	GREEN	YELLOW	YELLOW	GREEN
4	CYAN	CYAN	GREEN	CYAN	CYAN
5	CYAN	CYAN	GREEN	CYAN	CYAN
6	CYAN	CYAN	GREEN	CYAN	CYAN
7	CYAN	CYAN	GREEN	CYAN	CYAN

The last three combinations contain only two colors, namely, yellow/green, yellow/cyan, and green/cyan for Combinations 3, 4, and 5, respectively. As mentioned previously, four colors are the maximum, but not necessarily the optimum, number. However, why two colors appeared to outperform three is still obscure. Nevertheless, after testing many combinations of two, three, and four colors, the listed variations of two colors seemed worth further evaluation.

PHASE II: EXPERIMENTAL DESIGN FOR TEST OF COLOR COMBINATIONS

While the preceeding evaluation was critical for picking several prospective color-intensity combinations, it was by definition, open to experimenter bias effects. Practical necessity dictated the method used in choosing color codes, though it was clearly not the optimal method in terms of experimental control. Phase II will be the controlled experimental test to determine if any of the color codes chosen actually produce enhancement of target detection performance. The design is straightforward and is patterned after several recent studies performed in the ADRF, especially that of DaRos and Daggett (1988).

SUBJECTS

Twelve adult male subjects will participate in this phase of the research. The only visual requirements are that they have normal color vision and approximately normal visual acuity, corrected or uncorrected. Color perception will be tested using a standard pseudoisochromatic plate test, such as the Dvorine Color Vision Test (published by The Psychological Corporation). The reason for this test should be clear. Color is the critical variable in the present study and it is not uncommon for individuals to have a mild color weakness of which they may be unaware. On the other hand, subjects' own reports of acuity will be accepted. While it is well known that corrective lenses often do not compensate for all deficits in visual acuity (Kantowitz and Sorkin, 1983), nevertheless, it is assumed that any minor deficiencies in acuity will distribute themselves approximately equivalently across the experimental conditions of the present study.

Six subjects will be chosen from the members of the Processing Branch of the Submarine Sonar Department (Code 2151) at NUSC/New London. These will comprise the inexperienced group (Group I), so designated because they were not trained as sonar operators and they had no prior experience with sonar under actual combat conditions. The remaining six subjects (Group E) will be experienced sonar operators presently on active duty or retired.

There are several reasons for these choices. First, all would have had at least some experience with the waterfall-type of sonar display that is of concern to the present research, either simulated

in the ADRF (Group I) or actual (Group E). Second, previous research (DaRos and Daggett, 1988) has shown that experienced sonar operators approach the task differently than other subjects. In particular, experienced operators tend to respond with a much higher proportion of false negatives. Additionally, as might be expected, their target detection performance was superior to that of inexperienced operators. This superiority, however, while consistent over all phases of the DaRos and Daggett study, was not particularly large and was reflected primarily in terms of speed of target identification rather than in accuracy.

Differences in speed and accuracy of target detection can easily be attributed to differences in training and experience. The basis for the huge difference (a factor of 3) in false alarm rate is less clear, although it too was probably due to specific training. For the sonar operator onboard a submarine, it is imperative that a potential target not be missed. False alarms, on the other hand, are of little consequence. Other subjects, lacking such training, probably approach the task more as a dual challenge to make as many correct responses and, at the same time, as few errors as possible. Thus, they are less likely to make false negatives.

Since the above differences were observed in the DaRos and Daggett study and since we simply do not know what might be the differential effects of experience upon the introduction of color, we thought it important to have both experienced and inexperienced subjects present.

DESIGN

Phase II will be a 2x6 mixed factorial design with the two levels of sonar experience outlined above as the nonrepeated measure and six color schemes as the repeated measure. The color schemes include monochrome and the five color combinations identified in Phase I and presented in table 1. Thus, each subject will be presented with a detection task involving each of the color codes.

APPARATUS

Subjects will be tested individually in the ADRF. The display and test parameters will be identical to those employed in the DaRos and Daggett study (1988), with the exception that six color codes

will be employed instead of the two levels of signal conditioning (normal versus processed), which formed the basis of that study.

PROCEDURES

The experiment will require twelve sessions per subject, two sessions with targets presented in each of the six color codes. While the second session with each code will not constitute an identical replica due to the random nature of target presentation, it will, nevertheless, provide both a much needed check on the reliability of performance under the different conditions of the study and a more stable performance measure for each subject under each condition. In order to partially counterbalance for progressive effects (learning, fatigue, etc.) sessions will be presented to subjects in a Latin Square design so that each subject in Group I and each in Group E will be exposed to a different sequence of color codes.

Each session will consist of a presentation of eight sets of target data. Each set of data consists of one to eight targets, the number being determined randomly. The signal strength of each target varies randomly between -5 dB and 0 dB. For each set of target data, the display scrolls at a 1 line per second rate for a total of 240 lines per set, which translates to a duration of 4 minutes per set. At any given instant, however, a maximum of 60 lines of data are displayed.

During the presentation of each data set, the subject's task is to visually track the display and as soon as an apparent target is detected, move a trackball controlled cursor to the target and click the ENTER button above the ball. This results in a cursor image being left at the site of the apparent target and the automatic recording of relevant performance data. There are basically two types of performance data, i.e., accuracy and speed. Accuracy is indexed by whether the response was a hit or a false alarm. If it was a hit, speed is indexed by how many lines of target data were required for the target identification.

DATA ANALYSIS

As indicated previously, the present study is a 2x6 mixed factorial design, so the appropriate initial analysis would be a 2x6

mixed factorial analysis of variance (ANOVA). One such ANOVA will be computed on each set of performance data, namely, hit rate, false alarm rate, and average line count. Additionally, individual analyses will be employed as necessary to tease out as much information as possible from the data.

CONCLUSIONS

Although color is currently used for alphanumeric and graphic displays in advanced sonar systems, there has been no systematic use of color for the improvement of target detection in sonar gram displays. Because of the unique characteristics of these displays, the improper use of color could be extremely detrimental. However, a properly designed and controlled experiment comparing color coding with monochrome in a dynamic sonar detection display has yet to be performed.

The results of the present investigation suggest that color, if employed in a manner that avoids several problems characteristic of gram displays, may have the potential to improve target detection performance. A two-phase study was proposed to identify specific color codes that do exactly that, and then to evaluate them against monochrome. The first phase required the creation of a CTD to allow simultaneous presentation of color and monochrome sonar displays. The CTD was set up in the ADRF and used to select the set of color combinations presented in this report. Additionally, an experimental design was presented for Phase II, the controlled evaluation of the color combinations. The research and preliminary analysis presented in this report suggest that the experiment proposed for Phase II should be conducted, as it might finally answer the question of whether color coding can improve target detection in passive sonar displays.

BIBLIOGRAPHY

Aiba, T. S., and G. W. Granger, "Colour and Position Processing in Human Visual Perception," Japanese Psychological Research, vol. 27, no. 2, 1987, pp. 97-108.

Butler, W. B., and W. M. McKemie, Engineering Guidelines for the Use of Color in a Sonar Display, Tracor Sciences and Systems Document No. T73-AU-9550-U, 1974.

Carter, R. C., "Visual Search with Color," Journal of Experimental Psychology, vol. 8, no. 1, 1982, pp. 127-136.

Carter, E. C., and R. C. Carter, "Color and Conspicuousness," Journal of the Optical Society of America, vol. 71, no. 6, 1981, pp. 723-729.

Christ, R. E., "Review and Analysis of Color Coding Research for Visual Displays," Human Factors, vol. 17, no. 6, 1975, pp. 542-570.

DaRos, D. A., and T. A. Daggett, "Improved Signal Detection in Noise Using Image Processing Techniques in Sonar Displays" (in preparation), 1988.

French, R. S., Grey-Scale Versus Color Coding of Acoustic Data Images, NOSC-TR-207, 1978.

Hansen, O. K., Color Display Technology for the Submarine Advanced Combat Systems (SUBACS): A Human Factors Engineering Review, Hughes Ground Systems Group and I.B.M. Federal Systems Division Report, 1980.

Infante, C., "Ultimate Resolution and Non-Gaussian Profiles in CRT Displays," Proceedings of The Society for Information Display, vol. 27, no. 4, 1986, pp. 275-280.

Kantowitz, B. H., and R. D. Sorkin, Human Factors: Understanding People-System Relationships, NY: Wiley,1983.

Kehoe, E. J., "Selective Association" in Compound Stimulus Conditioning with the Rabbit," in Classical Conditioning (3rd Ed.), I. Gormezano, W. F. Prokasy, and R. F. Thompson (eds.), Hillsdale, NJ: Lawrence Erlbaum Associates, 1987.

Kelly, K. L., "Color Designations for Lights," Journal of Research of the National Bureau of Standards, vol. 31, 1943, p. 271.

Kraiss, K. F., and K. H. Kuttelwesch, "Color and Grey Scale in Sonar Displays," Society for Information Display 84 Digest, 1984, pp. 68-71.

Krebs, M. J., and J. D. Wolf, J. D., "Design Principles for the Use of Color in Displays," Proceedings of The Society for Information Display, vol. 20, no. 1,1979, pp. 10-15.

Krebs, M. J., J. D. Wolf, and J. H. Sandvig, Color Display Design Guide, ONR-CR213-136-2F, Honeywell Systems and Research Center, Minneapolis, MN, 1978.

Murch, G., "The Effective Use of Color: Cognitive Principles," TEKniques, vol. 8, no. 2, 1984, pp 25-31.

Neri, D. F., and D. Zannelli, "Guidelines for the Use of Color in SUBACS A Displays," Joint Report of NSMRL/Groton and NUSC/New London, 1984.

Poulton, E. C., and R. S. Edwards, "Search for Noisy Tracks Camouflaged by Noisy Backgrounds in Colour or Black and White," Ergonomics, vol. 23, no. 3, 1980, pp. 277-293.

Salafia, W. R., "Pavlovian Conditioning Information Processing, and the Hippocampus," in Classical Conditioning (3rd Ed.), I. Gormezano, W. F. Prokasy and R. F. Thompson (eds.), Hillsdale, NJ: Lawrence Erlbaum Associates, 1987.

Santucci, G., J. P. Menu, and C. Valot, "Visual Acuity in Color Contrast on Cathode Ray Tubes: Role of Luminance, Hue, and Saturation Contrasts," Aviation, Space and Environmental Medicine, vol. 53, no. 5, 1982, pp. 478-484.

Silverstein, L. D., "Human Factors for Color CRT Displays," The Society for Information Display, International Seminar/Symposium/Exhibition, San Diego, CA, 1982.

Solomon, P. R., "Neural and Behavioral Mechanism Involved in Learning to Ignore Irrelevant Stimuli," in Classical Conditioning (3rd Ed.), I.

Gormezano, W. F. Prokasy and R. F. Thompson (eds.), Hillsdale, NJ: Lawrence Erlbaum Associates, 1987.

Teichner, W. H., "Color and Visual Information Coding," Proceedings of The Society for Information Display, vol. 20, no. 1, 1979, pp. 3-9.

Volkov, G., "Effects of Shadow Mask Color vs. Monochrome CRTs on Detection of Sonar Signals," Paper presented at the Society for Information Display International Symposium, Orlando, FL, April 1985.

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